CHAPTER 15

STRUCTURAL REHABILITATION AND RECONSTRUCTION

15.1 General

For bridge design, follow the design procedures in **AASHTO's Standard Specifications for Highway Bridges** and this manual. Refer to **AASHTO's Manual for Condition Evaluation of Bridges** for rating and evaluation procedures.

The Department uses the load factor method of design as defined in the **AASHTO Standard Specification for Highway Bridges**. The design procedures in **AASHTO LRFD Bridge Design Specifications** shall be used with the approval of the Bridge Design Engineer. Live load design for structures on Interstate highways shall be HS25 (HS20+25 percent), including the sections of the highways connecting to the Interstate highways.

15.2 Materials

15.2.1 Structural Steel

The material for all main load-carrying members of steel bridges subject to tensile stresses shall meet **AASHTO** requirements for notch toughness. Refer to **Section 10.3, Repetitive Loading and Toughness Considerations, in the AASHTO Standard Specification for Highway Bridges**. Normally, AASHTO M270M, Grade 345, structural steel is used; painting is required.

AASHTO M270M, Grade 345W, structural steel weathers to preclude the need for painting. Weathering steel may be considered for structures over high traffic volume roadways or railroads, where access for painting or repainting is limited or dangerous. The use of weathering steel will be evaluated on a case-by-case basis and is subject to approval of the Bridge Design Engineer. Refer to **FHWA Publication Forum on Weathering Steel for Highway Structures: Summary Report**. Weathering steel should not be used in corrosive environments where there is high humidity or high concentrations of chloride. It may be desirable to paint the ends of weathering steel beams near bearings and under joints.

15.2.2 Cast-in- Place Concrete

Portland cement concrete (f'_c = 4500 psi at 28 days) is used for concrete decks. Reinforcing steel meeting the requirements for AASHTO M31M, Grade 60, shall be specified. All reinforcing steel shall be protected with fusion-bonded epoxy. Epoxy coating conforming to AASHTO M284M shall be specified.

15.2.3 Precast Concrete

Concrete with an f'_c = 5000 psi is normally used for prestressed concrete beams. An increase to 6000 psi or higher is permissible where it is reasonable to expect that this strength will be consistently obtained. Reinforcing steel meeting the requirements for AASHTO M31M, Grade 60, shall be specified.

Normally, prestressing strands shall be high-strength 7-wire low-relaxation strand, with nominal ½ in. diameter, and conform to AASHTO M203, 270,000 psi grade, low-relaxation strands. Minimum strand spacing (center-to-center of strand) will be four times the nominal strand diameter.

Epoxy coating is not normally specified for prestressing strands, but may be justified in areas where flooding may inundate the bottom of the superstructure. On post-tensioned structures, the designer will specify that all strands will be uncoated and all strand conduits will be pressure-grouted.

15.3 Reinforcement Steel

15.3.1 Reinforcement Presentation

Standard concrete cover in deck slab shall be 2½ in. for top reinforcement and 1½ in. for bottom reinforcement. Standard concrete cover for reinforcement in all other concrete members shall be 2 in. unless otherwise shown. Standard concrete cover shall be 3 in. for reinforcement in concrete surfaces in contact with ground unless otherwise shown.

Refer to the **Section 8.32, Splices of Reinforcement, in the AASHTO Standard Specifications for Highway Bridges** for splicing requirements. Normally, reinforcing steel splices are lapped and tied, but the designer may specify mechanical splices.

If there are transportation problems, the longest reinforcing bars may be limited to 60 ft. Specify long bars, insofar as possible, to minimize splicing. The minimum size of reinforcing is a Number (#) 5 bar.
When detailing lengths of reinforcement bars, consideration must be given to transportation and handling, and where extremely long lengths are contemplated, to availability and special orders. All sizes of bars are readily available in lengths up to 60 ft. However, #3 and #4 bars more than 40 ft. long tend to bend in handling; therefore, they should be avoided. Sizes #5 through #18 in lengths exceeding 60 ft. can be rolled at

mills by special order; 70 ft. should be considered the practical limit in any circumstance.

When the location of bar splices is arbitrary, as in the case of the longitudinal reinforcement of deck slabs on stringers, the following maximum lengths are preferred:

#6 bars and up..50 ft.
#5 bars...40 ft.
#4 bars ....30 ft.

15.3.2 Reinforcement Designation

- The following illustrates detailing notations:

  #5 - @ 18 in. ctrs.
  #5 - @ 18 in. ctrs. (FF)
  #5 - @ 18 in. ctrs. (RF)
  #5 - @ 6 in. ctrs. (T)
  #5 - @ 6 in. ctrs. (B)

- Explanation of abbreviations shall be noted on the plans:

  LEGEND

  (FF) Indicates Front Face
  (RF) Indicates Rear Face
  (T) Indicates Top
  (B) Indicates Bottom

The dimension of all laps shall be shown on the plans. When epoxy coating is required on rebar, "Epoxy Coated" shall be noted. When galvanizing is required on rebar, “Galvanized” shall be noted. Hooks and bends shall conform to the standards of the Concrete Reinforcing Steel Institute (C.R.S.I.). Avoid the use of hooks and provide 90 degree bends in lieu of hooks.

Other reasonable systems of bar designations will be considered for approval on an individual project basis. The Designer shall designate which corrosion protective system is to be used. Placement of epoxy coated and galvanized reinforcement in a single structural unit should be avoided.

15.4 Bridge Type Selection and Geometrics

The design criteria include levels of service, roadway classification, design speed, traffic volumes, traffic composition, and traffic projections. The designer should consider the need for future widening. The impact on traffic and construction operations at the time the structure will be widened must also be considered. If the widening will be required in the immediate future (less than 5 years), the substructure should be included in the original design, and may be built during the original construction.

The longitudinal joint in the deck should not be in a wheel path after the deck is widened. The widths of shoulders may be narrowed on long bridges to reduce costs. A long bridge is defined as being longer than 200 ft.; refer to **Chapter Seven in AASHTO's A Policy on Geometric Design of Highways and Streets** for the criteria. Narrowing or eliminating shoulders below AASHTO standards requires a design exception and must be approved by the Chief Engineer.

When reconstructing or rehabilitating the historic bridge structures, every effort shall be made to preserve the original shape and the use of original texture and type of materials. The construction plans must have an approval from the State Historic Preservation Office (SHPO) and the District's Commission on Fine Arts.

Engineering, architectural (when warranted), and cost studies shall be prepared for each structure or group of structures. Where several structures are in close proximity with each other, studies may be prepared to show possible interaction with each other.

In consideration of the need for a movable bridge structure, the long-term investment associated with machinery maintenance, liabilities associated with navigation hazards, and staffing the structure with operators should be considered. Also, the impact of traffic congestion due to openings should be considered. These issues should be addressed in assessing the cost and practicality of a movable bridge versus a fixed bridge.

These initial studies should be developed from a careful appraisal of the site, foundation, drainage conditions, highway limitations, and environmental impact, both present and future. The structural types proposed as a result of these studies must be based on the highest standards of creativity and engineering technique.

Economy, aesthetics and maximum safety are not incompatible in the design of structures. For grade separation structures, the absence of shoulder piers allows for possible future widening of the lower roadway while removing sight line restrictions and minimizing safety hazards. The resultant "open" structure usually results in a more pleasing appearance.

In planning new bridges, the list of available structure materials and types of construction should be considered. At any given location, the ultimate selection should be based on suitability and aesthetics. This is with consideration of the bridge and its site as an entity and also as part of the surrounding environment.

The character and coloration of the terrain and the form of nearby structures should all be influences on the aesthetics proposed for the structure.

Superstructures of shallow proportion shall be strived for; however, stiffness requirements and other design considerations must be balanced against those of aesthetic appeal. Unsightly details, which present abrupt discontinuities in the bridge profile, should be avoided.

In arriving at span proportions, substructure elements should be positioned clear of traveled roadways. Concrete piers that are built near roadways should generally be of open-type construction (i.e. column bent piers). When supporting a multitude of closely spaced stringers, a common and simple frame consisting of a uniform depth cap beam on circular columns may be suitable. Often times, frame proportions are enhanced by allowing the cap beam to cantilever over the exterior columns with a variable depth that tapers to a minimum beyond the fascia stringer bearing. The slender tee-pier should not be overlooked for the support of high crossings or narrow structures.

New designs, as well as major rehabilitation work for high level or complex structures, should include permanent provisions for inspection, such as catwalks, in order to make bridge members accessible. Bridge design engineers must avoid designs of, especially pin-hanger assemblies, fatigue prone, and fracture critical structures all new bridges shall be designed for redundant structures.

15.5 Geometrics on Bridges

The designer should minimize the skew angle of the substructure and the superstructure for simplicity of design and construction. Highway and bridge designers shall make every effort to eliminate or minimize adverse geometrics on bridges; such as, horizontal curves, vertical curves, variable bridge widths for on and off ramps, variable cross-slopes and many others. Curved bridges are generally more costly than straight bridges. For steel girder superstructures, heat curving the girders or cutting flange plates to meet the curvature will add to the steel cost.

Wherever possible, vertical curves, both crest and sag, should be located away from the bridge. It is economically advantageous to place a bridge on a tangent grade rather than on the vertical curve. Cambering girders for vertical curvature is more costly than tangent girders since excessive camber may entail cutting the web to the required curvature, thus wasting steel and increasing fabrication costs. Increased construction costs will result from forming a bridge deck on a curve in view of the additional labor required to achieve the plan precision in forming the deck.

A comprehensive and diligent analysis must be made of the entire project at the preliminary design stage. This should be the basis for designing curves and ramps away from the structures to the maximum extent feasible since they generally increase the bridge cost. Locating curves and ramps on the approach highways rather than on bridges results in simpler construction, is more economical, and reduces future maintenance requirements.

15.6 Vertical Clearance of Structures

15.6.1 Overhead Structures over Roadways

Minimum Vertical clearance = 14.5 ft

15.6.2 Overhead Structures over Interstate System

Minimum vertical clearance = 16.5 ft.

15.6.3 Overhead Structures over Freeways and Sections of the Highways Connecting to Interstate System

Minimum Vertical clearance = 16.5 ft.

15.6.4 Pedestrian Overhead Structures over Roadways

Minimum Vertical clearance = 17.5 ft

15.6.5 Overhead Structures over Railroads

Minimum Vertical clearance = 23 ft. or as directed by the railroad company

15.7 Alternate Designs

Studies during the Preliminary Design may conclude that alternate designs may be warranted for major bridges. The decision as to whether or not to proceed with an alternate design will be made, as recommended by the Project Manager in consultation with the Federal Highway Administration.

15.7.1 Existing Overhead Sign Structures

The existing overhead sign structures on freeways are based upon the steel pipe standards developed by U.S. Steel in the 1960's. If replacing is needed, they should be designed with a more aesthetic design, similar to the sign supports found at, as an example, the D.C. approach to the Theodore Roosevelt Bridge and Sousa Bridge. The design is a less industrial looking square tube design, and is approved by the Commission of Fine Arts.

15.8 Life Cycle Cost Analysis

A Life Cycle Cost Analysis (LCCA) is defined as the total cost of an item's ownership over a specified period of time. This includes, as applicable, initial acquisition costs (ROW, planning, design, construction), operation, maintenance and modification, replacement, demolition, financing, taxes, disposal, and salvage value.

An LCCA to compare the benefits and costs that arise at different times in a bridge structure's life span shall be made in studying alternate design concepts. Future benefits and costs over the proposed time span of each alternative should be considered. A long-term perspective should be considered in programming improvements and selecting among alternative design, maintenance, rehabilitation and reconstruction strategies in designing bridge structures.

An important factor to consider in this process, especially in urban areas, is highway congestion. Investment decisions must consider the impact that is imposed on the traveling public in constructing bridge structures on congested highways. LCCA will help the Department to identify and explain the real costs that it must bear in maintaining its bridge structures. Also, the LCCA will assist the Department in making the best use of available funds.

The following paragraphs provide guidance in developing the principals for a good LCCA. These principals will allow the Department to identify its investment alternatives.

- Design Life - Generally a longer design life should be considered for bridge structures. This is due to the realization that future Department and user costs, that are associated with maintenance of a bridge structure, will be high. For a bridge structure on the National Highway System (NHS) a design life of 100 years should be considered. This will require a longer analysis period. All project alternatives should consider this length.
- User Costs - The costs and lost productivity to the public because of traffic delays should account for a high cost range consideration. Increased vehicle

operating costs, accident costs and delay related costs should be considered in the LCCA.

- Discount Rate - Future agency and user costs should be discounted to net present value or converted to equivalent uniform annual costs using appropriate discount rates. The selected discount rate should be based on guidance that is provided in the Office of Management and Budget (OMB) Circular A-94, "Guidelines and Discount Rate for Benefit Cost Analysis of Federal Programs".
- Other Factors - Budgetary, environmental and safety considerations will influence the investment decision. These factors should be considered along with the results of the LCCA in evaluating the investment alternative.
- Department Costs - Traffic control costs, during a maintenance or rehabilitation project, should be considered in the LCCA.

15.9 Reconstruction and Rehabilitation

15.9.1. Eligible Work

Reconstruction and rehabilitation procedures necessary to assure acceptable performance of existing structures are set forth below and are eligible for Federal-aid participation from the appropriate category. Reconstruction and rehabilitation shall include all work required to assure satisfactory performance of the concrete deck, as well as supporting superstructure and substructure units.

- This may include items such as the removal of existing overlays, removal and replacement of all deteriorated components or the complete removal and replacement of the entire bridge deck if necessary.
- This work may also include repair or removal and replacement of deteriorated concrete curbs, sidewalks, parapets, as well as rail, deck joints, bearings, or similar incidental items which are associated with proper functional restoration of the structure.
- Safety improvements should be undertaken with the work mentioned above when such improvements eliminate an established hazardous condition. Such safety improvements may include widening, elimination of hazardous walks and substandard safety hardware, removal of hazardous fixed objects or the installation of energy absorbing barrier system, and any other features that are consistent with current safety standards.

15.9.2 Field Condition and Appraisal Survey

Where an existing bridge or structure is to be widened, altered, reconstructed or rehabilitated, review any existing report in the Department. In conjunction with the review of the Report, a limited Field Condition Survey may be required to update the original inspection report. The supplementary report shall include recommendations for remedial work together with the preliminary cost estimate. The Field Condition and Appraisal Survey shall be submitted prior to submission of the Preliminary Plans.

Safety improvements shall be considered for all reconstruction and rehabilitation projects. The minimum vertical under-clearance shall be measured and noted, together with its location, in the Field Condition and Appraisal Survey. If the under-clearance is substandard, a commentary about the extent of work that is needed to improve the situation, together with a preliminary cost estimate, shall be included. The Department will determine if a detailed retrofit study is warranted.

15.9.3 Concrete Bridge Decks

In the processes that are involved in construction, rehabilitation, and reconstruction of concrete bridge decks, with special emphasis on overlay protective systems, the following terminology shall apply:

- Construction - the initial construction of any specific bridge deck.
- Maintenance - routine or incidental work necessary to keep a bridge deck functioning in a safe and efficient manner.
- Overlay Protective System - a system used to protect bridge decks from deterioration induced by highway deicing chemicals, salt water, or other hostile environments.
- Reconstruction - the restoration of the structural integrity of a concrete bridge deck by complete removal and replacement of the existing deteriorated bridge deck.
- Rehabilitation - the work necessary to restore the structural integrity of portions of the original bridge deck as well as the installation of a deck protective system.

The following policies are established for all bridge decks to be constructed, rehabilitated, or reconstructed.

15.9.3.1 Overlay Protective System

The Department specifies quality concrete, epoxy-coated reinforcing steel, and extra cover over the top mat of reinforcement to ensure long-lasting decks. Additional deck protection, such as overlays, may be warranted on a case-by-case basis. Overlays may be justified on new decks where replacement of the deck would be very costly, or where traffic would be severely impacted during deck replacement. Overlays may be latex-modified concrete, silica fume concrete, or others approved by the Department.

The type of overlay protective system shall be one of the followings:

- Low Slump Concrete for thickness 2 in. and over
- Latex Modified Concrete or Microsilica Concrete for thickness under 2 in.

15.9.3.2 Superstructure Reconstruction Replacement

- The dead loads from the new slabs may introduce additional Dead Load stresses in the existing stringers and/or beams.
- If calculations indicate that the existing stringers and/or beams are overstressed, the matter, together with recommendations, should be brought to the attention of the Chief Transportation Engineer.
- Special measures such as requiring retrofitting stringers with shear connectors may be required.
- Additionally, the height of shear connector studs on the existing stringers should be considered. Additional studs may have to be added.

15.9.4 Special Conditions

Any changes in the condition of the bridge structure prior to opening of bids for construction that may impact the structural integrity of the bridge must be considered for incorporation in the construction plans. Special Provisions will be required for the following:

- Construction Staging.
- Traffic controls and diversions.
- Authorized detours.
- Restricted working hours or days.
- Load restrictions for construction equipment.
- Posting for reduced speeds, substandard vertical under-clearances and/or load capacities.

15.10 Bridge Deck Rehabilitation

15.10.1 Requirements

- Review the Bridge Evaluation Survey Report or any prior Deck Evaluation Survey.
- Perform an on-the-site observation to determine if a Bridge Deck Evaluation Survey is warranted.
- Perform, if authorized, a Deck Evaluation Survey.
- Perform a Field Survey to determine existing/as-built geometrics and deck profile elevations at 3-meter intervals (if warranted).
- When the superstructure is substandard in load capacity or vertical under-clearance a determination as to whether a retrofit study is warranted shall be made.
- The area of deck that is to be rehabilitated shall be designated as the area that is actually realized from the Deck Condition Survey or, as a minimum, 15 percent of the entire deck area.

15.10.2 Machine For Concrete Deck Overlay Protective Systems

At this time, concrete overlay protective systems shall include Latex Modified Concrete, low slump concrete and Silica Fume Concrete. Specifications require the use of a finishing machine for placing overlays. However, the Specifications also provide that "Hand operated vibrators and screeds may be used to place and finish small areas of work".

In some instances small "tight" areas, unusual transitions, or other geometric constraints may preclude machine finishing (minimize bridge deck areas that could preclude use of machine finish). Show on the plans in bridge deck areas and special provisions where adverse conditions could conceivably preclude the use of machine finishing:

15.10.3 Value Engineering

The use of Value Engineering (VE) in the planning, design and/or construction of structural work is encouraged. Consideration of life cycle cost shall be the primary purpose in applying VE to structural work.

Value Engineering is an effective tool for both product improvement and cost reduction. It should not be confused with the typical design review process nor should it be applied in a routine manner without warrant. Value Engineering should be employed when there is potential for a significant ratio of savings to the cost of the VE study or substantial improvements in program effectiveness. Value Engineering should be considered on all major structural projects, and on obviously high cost projects as well as standard details that are used repetitively on many projects.

For maximum benefit, VE should be employed as early as possible in the project development process so that valid VE recommendations can be implemented without delaying the progress of the project.

DDOT standards include a VE specification that encourages the Contractor to propose changes in contract requirements that will accomplish the project's functional requirements at less cost. The net savings of each proposal should be shared with the contractor, or through the Contractor with subcontractors and suppliers, at a stated reasonable rate. Reimbursement for such share is eligible for pro-rata reimbursement of Federal-aid funds. The Department retains the right to accept or reject all proposals and acquire all rights to use the accepted VE proposals in current and future projects without restriction.

15.11 Bridge Deck Evaluation Survey And Guidelines For Restoration Work

15.11.1 Deck Evaluation Survey

15.11.1.1 Description of Survey and Testing

Testing and evaluation of concrete bridge decks consists of visual observations, delamination or debonding detection, concrete sampling for chloride analysis, and electrical potential measurement (half-cell testing). All of these bridge deck evaluation techniques are used to detect existing defects and actively deteriorating conditions of the deck. The following description is intended to provide information and procedures for these bridge deck evaluation techniques. These techniques should be used in sequence and, if warranted, in combination. By using the combined results, engineers can better evaluate the condition of any bridge deck.

15.11.1.2 Visual Survey

The first step for deck evaluation is a visual observation to determine the extent of spalling, cracking and scaling. Visual observation, however, does not reveal hidden structural deterioration such as delaminations or corrosion of rebar. The information from visual surveys is used to determine further deck condition survey needs. Visual surveys are generally expressed in terms of the amount of spalling and patching as a percent of the total deck area.

15.11.1.3 Concrete Delamination Detection (Chain Drag)

A delamination survey provides information on the subsurface condition of concrete bridge decks. A chain drag can be used to survey concrete bridge decks for delaminations.

The chain drag consists of four or five segments of 1 in. link chain about 18 in. long, attached to a 24 in. piece of aluminum or copper tube, to which a 24 in. to 36 in. piece of tubing is attached at the midpoint, forming a "T". The chain is dragged along the surface of the concrete in a swinging motion, resulting in a ringing sound. When delaminated concrete is encountered, a noticeable "dull" sound is produced. The delaminated concrete area is outlined on the deck with chalk, crayon, or paint and can be plotted to give an overall picture of delaminated areas.

The results of the Chain Drag are not reliable when the bridge deck has been overlayed with bituminous concrete; therefore, its use is not recommended for bridge decks with bituminous concrete overlays.

15.11.1.4 Chloride Analysis

Chloride analysis provides a quantitative measure of the chloride ion contamination of concrete at selected levels in the deck. Concrete samples for chloride analysis, are usually taken by a rotary hammer drill. The concrete is pulverized in the hole from the combined hammering and rotating actions of the drill, thus facilitating removal and analysis. The sampling is done at or above the level of the top reinforcing bars, and the powdered concrete is collected and sent to the Department's Laboratory for analysis. The percentage of chloride ion is then calculated from the lab results. The "threshold" chloride content, or amount of chloride needed to initiate corrosion, is approximately 2.0 lbs of chloride per cubic yard of concrete.

15.11.1.5 Half-Cell Test

The purpose of half-cell testing is to determine the areas in the deck in which active corrosion is present. Corrosion of the reinforcing bars in concrete decks is detected by an electric current flowing from the rebar at one point (the anode) to another point (the cathode). During active corrosion, an electrical potential difference exists between the anode and cathode that can be measured by copper/copper sulfate half-cells (CSE).

The CSE is pure copper rod suspended in a saturated solution of its own ions. Corrosion of the reinforcing steel can be detected by grounding the CSE to the deck slab reinforcing steel, placing the CSE in contact with the Bridge Deck Electrolyte (i.e., touching it to a small section of deck wetted with water) and measuring the electrical potential from a volt meter attached to the CSE.

Research tests have demonstrated that potential differences more negative than -0.35 volts indicates a high degree of probability of active corrosion of the reinforcing steel. Potential readings not greater than -0.20 volts indicate the probability of inactive or no corrosion, while potential readings between -0.20 volts and -0.35 volts indicate the possibility of active corrosion. The potential readings collected are then used to plot an equipotential map of the deck and to estimate the percent area of the deck with actively corroding reinforcing steel. Surveys are temperature sensitive and should only be performed if the ambient air temperature has been above 40°F for a minimum of 72 hours immediately prior to the date of the survey.

15.11.1.6 Pachometer Test

In order to properly establish the deck condition, establishing the depth of cover over the top reinforcement is necessary. This will provide the evaluator with needed information to properly judge the existing condition versus what is the required minimum depth of cover.

15.11.2 Procedures to Perform Deck Evaluation Survey

15.11.2.1 Visual Observations

Make comments on the deficiencies of either the asphalt overlay or the concrete deck wearing surface (e.g. spalling, cracking, scaling, warping, asphalt creep, alligator cracks, etc.). Include the location and size of deficiencies, if any.

Observe the underside of the deck and record the approximate size and location of all areas exhibiting cracks with or without efflorescence. Also, record all areas having concrete spalled from the bottom reinforcing.

If the structure does not have asphalt overlay over the concrete deck, determine the percentage of spalls and/or patches in the exposed concrete deck-wearing surface. Decks covered with asphalt should be similarly inspected, with a general condition statement made about the asphalt surface. Record this percentage for use in the final deck condition determination.

15.11.2.2 Concrete Delamination Detection

15.11.2.2.1 Chain Drag

- Drag the chain in a swinging motion, while walking along the concrete surface of the deck.
- Outline, with crayon, the areas of the deck over which the chain produces a distinctive "dull" sound. These areas indicate delamination of concrete.
- Transfer the delineated areas on the deck by plotting on a scaled map of the bridge deck.

15.11.2.3 Chloride Analysis

- Select random sample locations for chloride testing using statistical methods and plot the locations on a plan view of the deck. As a minimum requirement, 10 locations per every 6000 sq. yd. area should be tested.
- Locate the depth of the top reinforcing steel with a pachometer to determine the chloride sampling depth.
- Cut out an approximate 1.0 sq. ft. section of bituminous concrete overlay, if any exists, to expose the concrete deck surface. Record the depth of overlay removed, if any.
- Obtain each of the random samples with a rotary hammer drill. Pulverize the concrete down to within ½ in. of the rebar location, vacuum the hole, pulverize approximately 1 in. of concrete, then collect the powdered concrete sample in an uncontaminated container. All of the samples should be properly labeled and sent to the Department's Laboratory for chloride analysis.
- After all of the holes have been drilled, and all the samples collected, refill the holes with materials similar to the material that was there prior to drilling, (i.e. concrete slabs with a fast curing "concrete compound" and asphalt overlays with asphaltic materials).
- After the lab has analyzed the samples taken, calculate the percentage of the samples with a higher chloride content than 2.03 lbs./cu. ft. from:

$$\frac{\text{No. of Samples with Cl. greater or equal to 2.03 lbs/cu.yd.}}{\text{Total No. of Samples}} \times 100 = \_\_\%$$

15.11.2.4 Half-Cell Test

- Test all equipment before proceeding to the field site. Check the Voltmeter battery for satisfactory charge.
- Measure and mark a 5 ft. grid pattern on the surface of the deck in accordance with Contract Plans. If a grid pattern is not shown on Contract Plans, the grid pattern should be recorded on a plan view of the deck for simplicity and speed in data recording. Start the grid with a 1 ft. offset from curb to keep the equipment out of the dirt and debris, and an offset from the first deck joint that will allow convenient placing of the grid pattern on the deck.
- Uncoil an ample length of wire to reach all the grid points to be tested and connect the copper sulfate half-cell (CSE) to the positive jack of the Voltmeter.
- Pre-wet the deck at the grid points with water, saturate a sponge with water, and attach it to the bottom of the half-cell.
- Begin to take readings of the electrical potentials at every other grid point with the half-cell and continue the testing until the whole grid pattern has been completed. The time it takes to get a stable reading will indicate the proper "soak" time for the deck. The Voltmeter needle should make an immediate response and settle down when good connections have been made. Note: If the deck is too wet or frozen, reliable readings cannot be taken.
- After the fieldwork is completed, the data can be recorded on graph paper and the equipotential lines plotted to produce an equipotential contour map.
- The percentage of possible corrosion affected deck area is then calculated from the results by counting the number of tests points equal to or more negative than -0.35 volts.

$$\frac{\text{No. of Samples More Negative than -0.35 volts x 100}}{\text{Total No. of Samples}} = \underline{\quad}\%$$

15.11.2.5 Pachometer Survey

- Pachometer Survey to determine the depth of the concrete cover over the reinforcement steel. The equipment shall be calibrated according to the equipment manufacturer's specifications.
- Locate and expose a reinforcing bar in the deck using a jackhammer. Connect the negative lead of the Voltmeter to the reinforcing steel. Connection can also be made to other metallic objects on the bridge (e.g. drainage scupper, light standards, bridge railing, expansion joints, etc.), if they are physically connected to the reinforcing steel. Connections should be made in

each span if the reinforcing steel is not continuous through the expansion devices.

15.11.3 Summary - Sample Calculations and Statements

The summary calculations show a composite result of the previously described tests as follows:

- Visual: The percentage of visual spalls over the top of the deck is 10 percent.
- Concrete Delamination Detection: The analysis of the data revealed that 65% of the tested area is delaminated.
- Chloride Analysis: The results of the chloride analysis (shown below) revealed that 60% of the samples tested were above the 2.03 lbs per cubic yd. threshold.

$$\frac{\text{Unacceptable Samples}}{\text{Total Samples}} = \frac{(6)}{(10)} = 60\%$$

- Half-Cell Test: The results of the half-cell testing (shown below) revealed that 13.5% of the tests taken were more negative than -0.35 volts.

$$\frac{\text{Unacceptable Samples}}{\text{Total Samples}} = \frac{(13)}{(96)} = 13.5\%$$

15.11.4 Composite Results

Starting with 100 percent of the deck and deducting non- duplicative contaminated areas from the tests above:

- Visual 100.0 - (100.0 x 0.10) = 90.0% Remaining uncontaminated
- Delaminations 90.0 - (90.0 x 0.65) = 31.5% Remaining uncontaminated
- Chloride 31.5 - (31.5 x 0.60) = 12.6% Remaining uncontaminated
- Half-Cell 12.6 - (12.6 x 0.135)= 10.9% Remaining uncontaminated
- Composite Result Final = 100.0 - 10.9 = 89.1% of the bridge deck tested had contaminated concrete.

15.11.5 Conclusions and Recommendations

The final category classification, using the percentage of bridge deck contamination shown in the summary, should be made in accordance with the Category Classification section within this chapter. The classification and evaluation of the deck should also incorporate engineering judgment in addition to the test results to provide a meaningful and complete recommendation for deck rehabilitation or reconstruction.

15.12 Guidelines for Determining Deck Condition and Extent of Work

Experience, judgment, and research have shown that deterioration often continues in partially rehabilitated decks when only the obviously deteriorated portion of the deck is removed and replaced. To minimize this effect, procedures are required that will determine the extent and type of rehabilitation or reconstruction that should be provided.

The following guidelines present procedures that should be considered in determining existing bridge deck conditions and the extent of work required for adequate rehabilitations. They also represent the current state-of-the-art on this subject and therefore will be updated as necessary when technology improves.

Although these are guidelines and are intended to be flexible, a great deal of care should be exercised in any significant deviation. In all cases, the rationale for any significant deviation should be explained in the project records or correspondence.

15.12.1 Field Condition Survey

A limited field condition survey should be made to identify bridge decks that may be structurally inadequate or possibly contaminated with de-icing chemicals such that normal maintenance is not expected to provide reasonable service. Some examples of deck slab conditions that may warrant rehabilitation and/or protective measures are as follows:

- Visible concrete spalls which have occurred in the deck riding surface and/or evidence of unsound concrete in the bottom exposed surface of the deck slab (which may indicate structural failure).
- Extensive deterioration of the asphaltic overlay logically due to underlying concrete deterioration.
- Evidence of delaminations (horizontal fracture planes) in the concrete deck.
- Evidence of reinforcing steel corrosion.
- Evidence of inadequate concrete cover over the reinforcing steel.

15.12.2 Structural Adequacy

When the structural adequacy of a bridge deck to carry current traffic loads is questioned, an in-depth field survey and analysis must be performed. This review should determine the extent of deficiencies as well as the feasibility of rehabilitation. Economics, traffic maintenance, etc., need to be evaluated when balancing the feasibility of structural restoration against complete replacement.

15.12.3 Detailed Field Appraisal

Where the field condition survey has indicated that rehabilitation and/or reconstruction may be warranted, a detailed Evaluation Survey should be performed to further define the inadequacies of the existing deck. This appraisal should, to the extent appropriate, consider the following as recommended components of an evaluation system:

- Delamination detection with appropriate equipment to determine extent of internal fractures of the concrete.
- Determination of the extent of reinforcing steel corrosion by the use of a half-cell corrosion detection device.
- Determination of areas with inadequate concrete cover over the reinforcing steel by the use of appropriate equipment.
- Chemical analysis to determine extent of chloride contamination.

15.12.4 Evaluation of Field Survey Results

Research reports have explained the interaction of all current detection methods and emphasized the need to use each method only for its designed purpose. The following data have been developed by research and experience:

- Delaminations - The use of a chain drag will readily define the areas of loss of structural performance in the form of delaminations or cleavage planes within the concrete. This normally indicates active corrosion of the rebar within these areas and probable chloride contamination of the entire deck. A visible spall is the end result of delaminations at the level of the rebar.
- Electrical Potential - Laboratory corrosion tests and field experience have shown that there is a 95 percent probability that an electrical potential in excess of -0.35 volts (CSE) to the copper-copper sulfate electrode corresponds to active corrosion in the reinforcing steel. However, this does not necessarily provide any positive relationship to the destructive nature of the corrosion that is occurring.
- Concrete Cover - Chloride concentrations are significantly greater near the surface of a concrete bridge deck. When rebar has less than

specified concrete cover they become appreciably more susceptible to damaging rebar corrosion.

- Chloride Content - Test results have generally established that the corrosion threshold is approximately 2.0 lbs of chloride per cubic yard of concrete at the level of the rebar for typical bridge deck concrete.

15.12.5 Category Classification

The limits describing three categories of condition as described below are based on the best judgment available nationally.

The user will note that Category 2 will in many cases overlap Category 1. In such cases the District will exercise its best judgment based on engineering, economics and other factors to properly categorize a given bridge deck.

15.12.5.1 Category 1 - Extensive Active Corrosion

5 percent or more of the deck area spalled

OR

40 percent or more of the deck area deteriorated or contaminated as indicated by any nonduplicating combination of the following:

(1) spalls, (2) delamination, and (3) corrosion potentials more negative than -0.35 volts (CSE)

OR

40 percent of the area of the bridge deck indicated by random chloride sampling to contain greater than 2.0 lbs of chloride per cubic yard of concrete at the level of the top rebar.

15.12.5.2 Category 2 - Moderate Active Corrosion

0 to 5 percent of the deck area spalled,

OR

5 to 40 percent of the deck area deteriorated or contaminated as indicated by any nonduplicating combination of the following: (1) spalls, (2) delaminations, and (3) corrosion potential more negative than -0.35 volts (CSE),

OR

5 to 40 percent of the area of the bridge deck indicated by random chloride sampling to contain greater than 2.0 lbs of chloride per cubic yard of concrete at the level of the top rebar.

15.12.5.3 Category 3 - Light to No Active Corrosion

No spalls,

OR

0 to 5 percent of the deck area deteriorated or contaminated as indicated by any nonduplicating combination of the following: (1) delaminations, (2) corrosion potentials more negative than -0.35 volts (CSE),

OR

0 to 5 percent of the area of the bridge deck indicated by random chloride sampling to contain greater than 2.0 lbs of chloride per cubic yard of concrete at the level of the top rebar.

15.13 Recommended Restoration Procedures

Based on the foregoing categorization of the condition of the bridge deck, the table below, which details rehabilitation and reconstruction alternates, has been developed.

15.13.1 Testing Steps

- Visual
- Delamination
- Electrical Potential
- Pachometer Survey
- Chloride Content

15.13.2 Restoration Procedures Chart

Category	Procedures	Restoration (Considered Permanent)	Restoration (Estimated extended life 10 to 15 yrs)
Structurally Inadequate		Complete Deck Replacement (Unless restorable)	
Extensive	Required	Complete Deck	Removal of all deteriorated concrete.

Active Corrosion (1)	Restoration Work	Replacement	Follow the repair procedure approved for the protective system selected.
	Testing	Steps 1 through 5 as necessary. (Probably only steps & 2)	Steps 1 & 2 only, except all the testing steps on the first five (5) bridge decks (spans) plus 10 percent of the remaining bridge decks.
	Suggested Protective Systems	Membrane with bituminous concrete overlay*; Concrete Overlay Protective System. *	Concrete Overlay Protective System.*8
Moderate Active Corrosion (2)		Same as Category 1 above OR Same as Category 3 below, as determined by the State.	Same as Category 1
Light To No Active (3)	Required Restoration Work	Removal and Replacement of all areas of deterioration and chloride contaminated concrete as determined by corrosion potentials and/or chloride sampling. (Less than 5 percent of the deck area is bad).	Same as Category 1 Note: For this category of condition, permanent restoration is recommended.
	Testing	Steps 1 through 5.	Same as Category 1
	Suggested Protective System	Membrane with bituminous concrete overlay*; Concrete Overlay Protective System.*	Concrete Overlay Protective System.**

* When approved prior to Preliminary Plan

** Submission on a project-to-project basis